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MANUAL DEXTERITY AND TACTILE SENSITIVITY IN THE COLD

by

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This report has been arranged in two Parts to bring out as clearly as possible both the main experimental conclusions that appear to be justified and the degree to which they are supported by statistical analysis. Part I is descriptive. Part II contains the detailed statistical analysis.

SUMMARY

(1). Experiments have been carried out to ascertain the effect of cold conditions on the performance of tasks involving manual dexterity and tactile sensitivity.

(2). In a pilot experiment at room temperature, 4 manual dexterity and 3 tactile sensitivity tests were given to 20 subjects. Subsequent correlations between pairs of tests of the same kind showed there was no statistical justification for eliminating any of the manual dexterity tests. Of the tactile sensitivity tests only one (the two-point discrimination test) was retained.

(3). 18 subjects were tested in the cold chamber and were divided into 3 groups of six:

Group A was exposed to a temperature of -10°C. for ½ hr with still air
Group B " " " -10°C. for 1 hr " " "
Group C " " " -10°C. for 1½ hrs. " " "

(4). In each group the tests were applied in a balanced design. Subjects were given pre-exposure, and exposure test runs, and on leaving the chamber each subject continued to perform the tests in rotation until his performance returned to near pre-exposure levels. Skin (finger) temperatures were recorded.

(5). To aid interpretation of the results of the first experiment, a second one was carried out using the two-point discrimination test at room temperature only. Groups A and C, and a third group (D) of 12 men not previously tested took part in this experiment.

(6). In a third experiment, 6 subjects (Group D) were given the tactile sensitivity test and one of the manual dexterity tests at intervals before entering the cold chamber, and during a 40-min. exposure period.

(7). In the first experiment all three groups of subjects showed significant impairment in performance in carrying out all the 4 manual dexterity tasks in the cold, with the exception of Group A, which showed a non-significant improvement on one of the tests. Performances deteriorated as the exposure period increased, showing more markedly with some tests, and with some subjects than others.

(8). All three groups showed improvement in tactile sensitivity during the first 30 minutes in the cold chamber. The performance of all three groups showed a tendency to return to pre-exposure levels of performance on leaving the chamber. Very significant differences were found between the performances of subjects in the same group.

(9). Skin temperatures were significantly correlated with length of exposure and with tactile sensitivity.

(10). In the second experiment average readings for Group D showed a steady improvement throughout the experiment, while those for Groups A and C maintained a fairly consistent level of performance. The results of the third experiment indicated that the improvement of tactile sensitivity in the cold found in the first experiment may be attributed to a 'learning factor'. Manual dexterity may be affected in a similar manner.

(11). Exposure to cold prevented the normal improvement in performance of manual dexterity tasks, taking place at room temperature. This did not occur in the case of tactile discrimination until a sudden lowering of the temperature was brought about, associated with the introduction of a wind factor.

PART ONE

THE PROBLEM

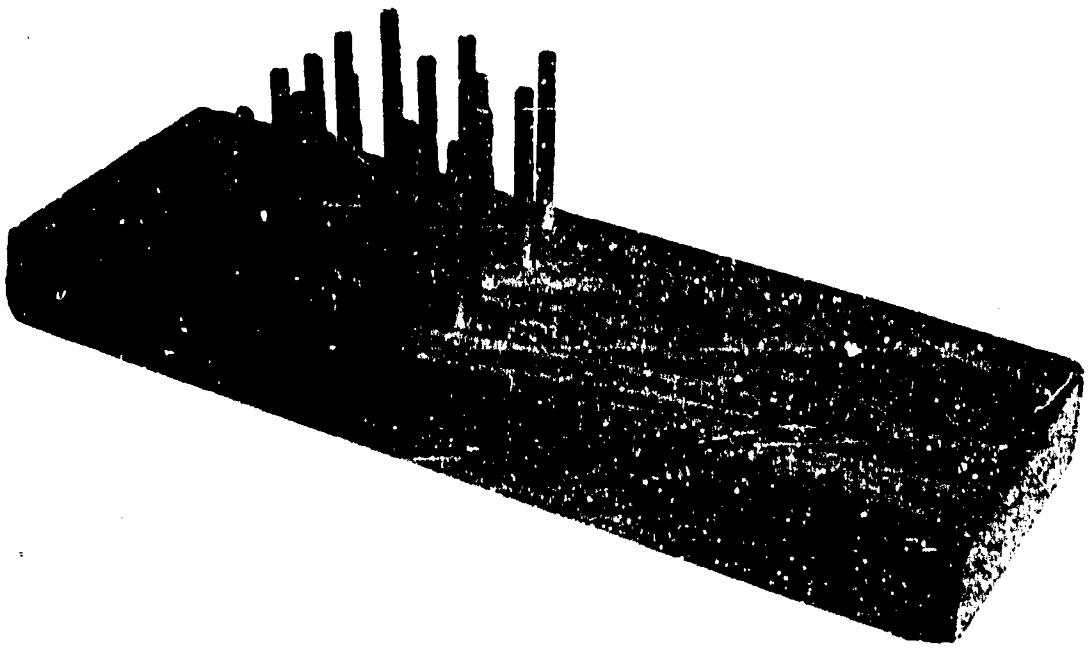
Many earlier experiments have shown that human sensitivity and volitional behaviour are adversely affected by exposure to severe cold, especially with wind. The present enquiry was undertaken in an attempt to discover more about the effect of less severe low temperature conditions on the same types of performance.

I. Description of the Tests

1. Manual Dexterity tasks

The Peg Test
The Nut and Bolt Test
The Screwdriver Test — screwing in
The Screwdriver Test — unscrewing

Plate (i): The Peg Test



In a block of wood 8" x 2½" x 1" two sets of 20 randomly arranged holes were drilled. The two sets of holes were separated by a 2" x 2½" space. The block of wood was held on the table by the subject's left hand, and he performed the test by transferring 20 pegs, 1/10" diameter, with his right hand from one set of holes to the other. All subjects used were right-handed.

Plate (vii): The V-test

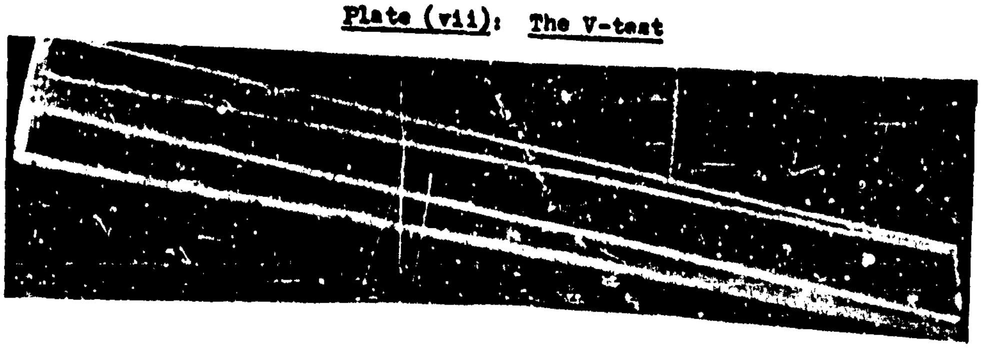
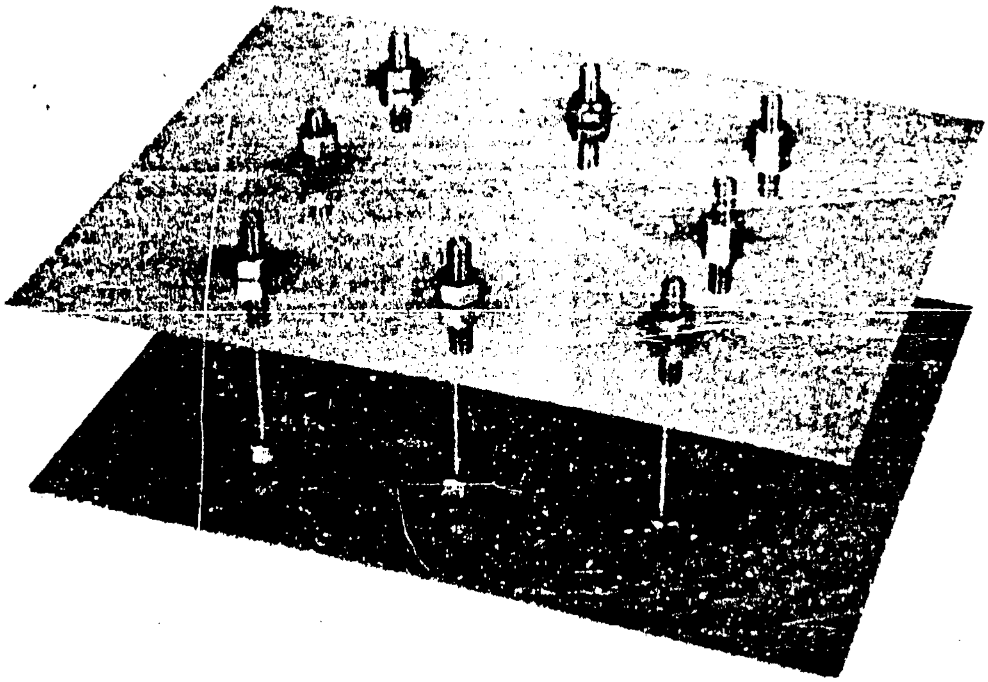
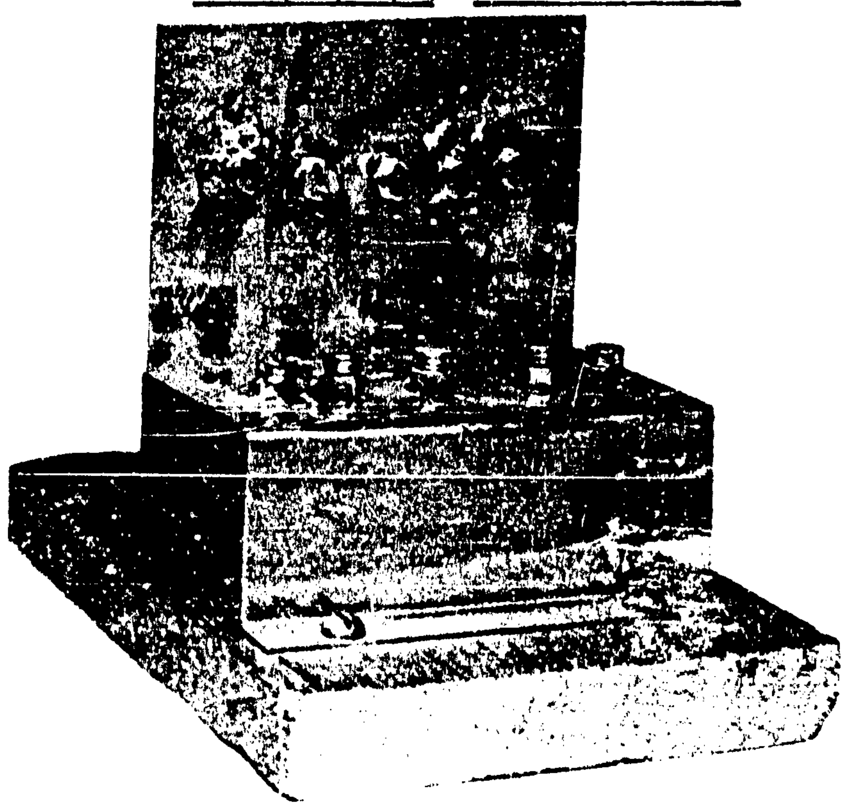


Plate (ii): The Nut and Bolt Test.



Consisted of two metal plates 4" x 3" in which 8, 1½" bolts were mounted in a regular square arrangement - 2" x 2". The plates were separated from one another by 1 2/10" so that the bolts projected 3/10" above the upper plate. Eight 6 B.A. nuts on each of the projecting portions of the eight bolts, which had been screwed down until they were in contact with the upper plate, had to be removed by the subject as quickly as possible while he held the apparatus on the table with his left hand.

Plate (iii) & (iv): The Screwdriver Test



Consisted of two metal plates 3" x 2" arranged at right angles, with two sets of five 4 B.A. nuts each set arranged in a row in the centre of one of the metal plates. In order to screw the ¼-inch bolts into the nuts, subjects were allowed to begin by screwing the bolt in with their fingers until the tip of the bolt was flush with the back of the metal plate, and the task was completed with a screwdriver. Unscrewing was carried out with a screwdriver, until the tip of the bolt no longer projected beyond the back of the plate, and thereafter the nut was removed by hand.

All tests had to be performed as quickly as possible. The "score" was the time taken to perform each task.

2. Tactile Sensitivity

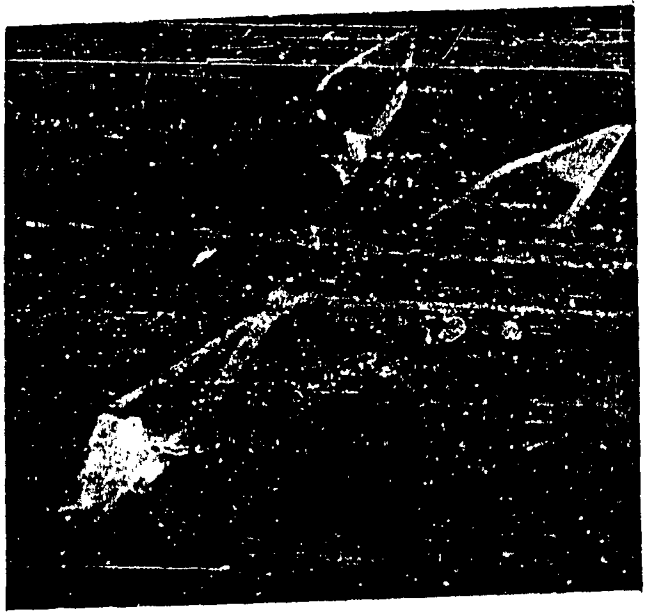
Two-point Discrimination (the Dividers Test) (plate v)

The Hole Test (plate vi)

The 'V-Test' (Mackworth 1951) (plate vii)

The apparatus for each of these was made up in perspex.

Plate (v): The Dividers Test

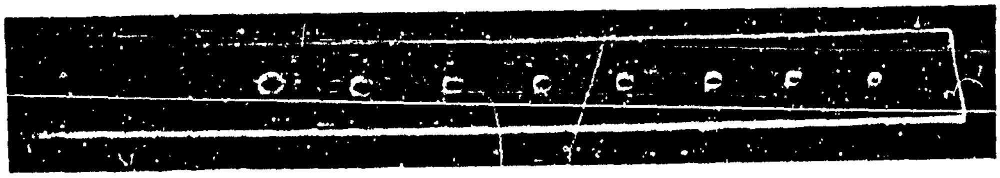


A two-point instrument 6 in. long similar to a pair of compasses was constructed. When applying the test the normal "Method of Limits" was used first in descending and then in ascending order, (i.e. the points were first applied widely separated and then brought nearer together, until the subject reported "one" point only.) The order of application was then reversed. The divider points were applied to the pulp of the subject's right index finger

During a run the subjects remained passive, the test being applied by the experimenter. No actual measure of the pressure with which the test was applied was made, though the experimenter endeavoured to maintain constant pressures, and was careful to apply the two points of the Dividers Test simultaneously.

One complete test consisted of 10 runs in each direction, the subject giving responses of "two" or "one" according to the sensation of the number of stimuli received. The test was scored by recording the last, or the first separation in each case, when the response "two" was given, and an average of the ten readings so recorded was taken as an indication of the subjects tactile sensitivity at the time of the test.

Plate (vi): The Hole Test



A strip of perspex was used in which a regularly graded series of holes of known diameter had been bored. The pulp of the subject's finger was applied to the perspex strip by the experimenter, and the test was conducted as for the Dividers Test, with the exception that the subject's response was "hole" or "no hole", and the reading recorded was the diameter of the hole last or first felt.

II. Selection of the Tests

Graded forms of each of the manual dexterity tasks were constructed - e.g. 4 different sizes of peg, 6 different sizes of nut, and 3 different sizes of bolt. These tests, together with the tactile sensitivity tests already described were given to 20 subjects in a pilot experiment at room temperature in order to ascertain whether any positive correlations in performance existed between tests, and also in an effort to eliminate some of the tests and so reduce the total time of trials under full cold conditions.

All subjects chosen were healthy males between 20 and 35, engaged in research work in the RAF Institute of Aviation Medicine.

The results of this experiment showed that in the case of the dexterity tasks each performance was reasonably independent of the others. Accordingly it was decided to retain all 4 tests.

In the case of tactile sensitivity there proved to be considerable overlap between all 3 of the forms used, as indeed might have been expected. It was therefore decided to adopt the Dividers Test chiefly becauseof its superior definiteness and the greater ease with which some control over pressure could be maintained. (See correlation values referred to above will be found in Tables I(a) and I(b),) Part Two)

III. General Conditions of the Cold Experiments.

1. Clothing: Civilian Subjects wore their ordinary winter underclothing, a heavy-weight Navy pullover, long black wool stockings, a kapok "inner-lining" for external protection, fleece-lined flying boots, a loose weave 'dish-cloth' scarf, a cold weather, wind-proof cap, a light-weight, wool lined and a cotton-backed glove for the non-preferred hand (i.e. the left hand in all subjects tested).

Service personnel wore exactly similar clothing, except that they wore battle-dress blouses, instead of the Navy pullover.

No form of protection was provided for the subjects' right hands.

2. The Cold Chamber: Conditions (-10°C. with still air) could not be maintained for longer than 30-40 min. in the experimental chamber. Consequently, as there was a continual upward trend of temperature, subjects actually entered the chamber at a temperature of -15°C., and when this rose to -5°C. (generally 30 minutes later) the refrigerating plant and electrical fan were turned on, to bring the temperature down to -15°C. again.

IV. Description of the Experiments.

1. Experiment 1., 18 of the 20 subjects already tested were chosen and divided into 3 groups of 6, on the basis of their average tactile sensitivity readings already recorded, so that each group contained an equal number of apparently "more" and apparently "less" sensitive subjects.

Group A was exposed to a temperature of -10°C. for ½ hour.

Group B " " " " " " -10°C. " 1 hour.

Group C " " " " " " -10°C. " 1½ hours.

The chosen tasks were applied in a regular, balanced design for each group, with the tactile sensitivity task always kept in the central position i.e. the third task performed.

The procedure adopted was to test every subject first at room temperature (15° to 18°C.) on the complete battery of tests, in order to establish a basic reading for that subject for each test. A skin-temperature reading was then taken with a copper-constantan thermocouple. The thermocouple was placed on the centre of the pulp of the exposed index finger, and kept in place with zinc-oxide strapping. After the reading had been taken the thermocouple was removed.

The subject then entered the cold chamber where he remained seated at rest throughout the exposure period. Tactile sensitivity recordings were taken at 10 minute intervals after entering the chamber, and skin temperature readings were taken before and after each recording.

Since the complete battery of tests took an average testing time of 20 minutes to complete, testing was commenced 10 minutes before the end of the exposure period, and continued for 10 minutes after that time, but since subjects differed considerably in the amount of time they took to perform the dexterity tests, in some cases they had to continue testing in the cold chamber for 15-18 minutes after the end of the exposure period. Skin temperature readings were taken before and after the final testing period in the cold chamber.

On leaving the cold chamber, the subject continued to perform each test in rotation until his performance level returned to the original value, or near the original value. Skin temperature readings were taken between each test.

2. Experiment 2: The subjects in groups A and C were re-tested, using the two-point discrimination test, at room temperature only. Group B was eliminated owing to the absence of some members of the group.

A third group of 12 subjects - Group D - was tested over a period of 60 minutes at room temperature. The individuals in this group had not taken part in the previous experiment, but were being tested for the first time.

The Dividers Test was applied as before. Subjects were tested at 10 minute intervals. The timing conditions were made to simulate those of the previous experiment, so that a 'pre-exposure level' reading was first taken, a period of 15 minutes allowed to elapse, and then testing was continued at 10 min. intervals for the requisite 'exposure' period until finally two so-called 'part-exposure' readings had been recorded. (Note: The test itself took 3-5 mins. to apply so that "testing at 10 min. intervals meant a testing period of 5 min. and a rest period of 5 min.

3. Experiment 3. 6 available subjects in Group D were tested at room-temperature at 10 min. intervals until their tactile sensitivity level seemed to have reached a fairly constant figure. They then put on the same cold-weather clothing as was used in Experiment I and entered the cold chamber. The same temperature (-10°C.) was used as in Experiment I. After commencing cold exposure, subjects were re-tested at 10 minute intervals until the temperature in the chamber rose sufficiently to require the electric fan and refrigerating plant to be turned on to restore the test conditions. This meant that cold exposure lasted for 30-40 minutes for most subjects, and the 'wind-chill factor' was eliminated. No skin temperature readings were recorded.

The Peg Test, shortest of the manual dexterity tasks to perform, was given to every subject after the tactile sensitivity reading had been recorded, both at room temperature and in the cold conditions.

V. The Experimental Results:

Experiment 1: Results: Manual Dexterity.

The average time curves for the ½ hr, 1 hr and 1½ hr groups (A, B, and C groups respectively) were drawn up from the absolute individual figures. (See Figures 1,2,3, and 4.)

In all groups with the exception, for all 4 tests, the average curves showed a definite impairment of performance at the end of the exposure period. The average curve representing the performance of the ½-hr group (Group A) on the Peg Test, shows that in fact at the end of the exposure period, performance had slightly improved, though the loss of 1.5 secs. on their original level at room temperature is not significant, showing that the exposure to cold had no effect on this group performing this test.

It was apparent from the individual curves that the performances of subjects varied considerably within groups, some subjects showing little or no change in performance level throughout the experiment, (e.g. one subject in Group B had a pre-exposure level of performance of 251 sec. test 3 of which rose to 253 secs. after 60 minutes exposure and finally dropped to 245 sec., 30 minutes after leaving the cold chamber), while other subjects show a very marked deterioration in performance (e.g. another subject in the same group, performing the same test, had a pre-exposure level of performance of 189 secs., which rose to 358 secs. after 60 minutes to exposure, and finally dropped to 185 secs., 30 minutes after leaving the cold chamber.)

Tables II(a), II(b), II(c) and III set out the relevant statistical data for this section of the report. The more important conclusions arising from the analysis were:-

(1) Performances deteriorated as the exposure period increased.
(2) Performances deteriorated more on some tests than others in the cold.
(3) Performances of some subjects within a group deteriorated more than those of other subjects.

Subjects' Comments:- Subjects in Groups B and C commented on the loss of power in the thumb, which appeared to them to be more pronounced than loss of sensitivity, and this observation was used by them to explain the increasing awkwardness and clumsiness in manipulation of the dexterity tests towards the end of the exposure period.
Craik observed in his work on 'Effects of Cold upon Hand Movements and Reaction Times' that "whereas normally the thumb can be rotated to face the fourth finger and extended to touch the tip of this finger without the latter bending at its inter-phalangeal joints, when cold the fourth finger is involuntarily bent to meet the almost helpless thumb, and the thumb fails to rotate, pressing sideways towards the fingers".

Both screwdriver tests were found to tax the powers of the subjects most, the greatest difficulty being experienced in endeavouring to pick up the bolts the correct way round, and insert them with a slight screwing motion into their holes.

Experiment 1 - Results: Tactile Sensitivity.

As in the case of manual dexterity, average curves for Groups A, B and C were drawn up from the absolute and relative figures (see Figures 5 and 6). (Note: The relative figures here are obtained by the method used by Mackworth in calculating his 'numbness index'. The initial readings on the Dividers Test taken before cold exposure differed between one man and another; the size of the just detectable gap varied from 1.55 m.m. in some subjects to as much as 2.7 m.m. in others. It was therefore necessary to remove the effects of these individual differences in normal tactile sensitivity when estimating the average effects of the particular chosen environment. For each person the difference between the initial reading of the just detectable gap and each of the subsequent gap sizes needed by that person was calculated. The 'tactile sensitivity index' was therefore the average decrease or increase required in physical gap size to keep the tactile impression of two separate, distinct points, and this average figure was the mean of readings taken from the subjects comprising a group.) In all 3 groups, the average curves showed a definite improvement in performance (i.e. a decrease in the physical gap size required to keep the impression of two points), which was maintained for the first 30 minutes of exposure. This improvement, although definite, was small, the largest decrease in average gap size for any group being 0.5 m.m. (Group B), and in actual gap size for any individual 1.3 m.m. (Group A). In both Groups A and C, the maximum improvement in performance was reached at the 30 minute level, and thereafter performance began to deteriorate. In Group B, the maximum improvement was reached after 20 minutes exposure, and again deterioration appeared after 30 minutes. Group C reached a fairly consistent level of performance after 50 minutes, but a second slight improvement occurred during the last 10 minutes of the exposure period.

The abrupt change in performance shown by all the average curves after the 30-40 minute level appears to correspond with the time at which the refrigerating plant and the electric fan were turned on again in order to reduce the temperature in the chamber. The change in performance seen in Group A corresponds with the end of their exposure to the cold conditions and their return to room temperature.

All three group average curves demonstrate the tendency to return to their original levels of tactile sensitivity on terminating their periods of exposure. Testing was continued for 30 minutes, or longer, with each individual after leaving the cold chamber.

Tables IV, V, VI(a) and VI(b) set out the relevant statistical data for this section of the report. There are significant differences between groups, between temperatures, and between subjects within groups, but whereas the improvement between pre-exposure and terminal exposure readings was definitely significant, the change in performance between terminal exposure and final post-exposure readings (illustrated in figs. 5 and 6) was found to be non-significant.

Subjects' Comments:- 10 of the 18 subjects performing the tactile sensitivity test commented on a sensation of increased sharpness or better definition of the points of the perspex dividers in the cold. This sensation commenced fairly soon (approx. 20 min.) after entering the chamber, and appeared to fade gradually after 40 minutes exposure.

2 subjects in Group C had some difficulty, after 60 minutes exposure, in differentiating the two divider points even at their maximum separation. This difficulty was associated with a subjective sensation of pain, extreme cold, and some stiffness of the fingers following the second exposure to the fan and refrigerating plant. Both subjects at this time, had a skin temperature of 4-4.5°C., the lowest skin temperature recorded for any individual during this experiment. Within about 10 minutes, however, a phase of vaso-dilatation occurred, and the ability to distinguish the points returned (Blaisdell 1951).

Tactile Sensitivity and Skin Temperature:

Group average curves from skin temperature readings were plotted together (Fig.7), and also with group average curves for tactile sensitivity, on the same time scale. In both Groups B and C a lag was present between the lowest point reached in tactile sensitivity performance and that reached by skin temperature (i.e. the lowest tactile sensitivity reading was recorded before the lowest skin temperature reading.) In Group A this phenomenon was reversed. The same relations between curves for all groups was maintained after the termination of exposure.

Skin temperature correlated directly with length of cold exposure. The lowest points reached on the group average curves were 10.8, 9.0 and 8.2° C. for Groups A, B and C respectively.

Skin temperature returned to pre-exposure levels more nearly than tactile sensitivity after terminating the exposure period in the cold chamber.

Table A. Average Initial and Final Skin Temperature Readings.

Group	Original Pre-Exposure level	Level 40 minutes after terminating exposure
A	31°C	31°C
B	32°C	31°C
C	32.5°C	29°C

Correlations between sets of readings of tactile sensitivity and skin temperature from the records of the 18 subjects were carried out. It was shown that there was a correlations almost significant at the 5% level, illustrating that improved performance on the two-point discrimination test was associated with a fall in skin temperature. 3.

2. Experiment 2 - Results.

Group average curves from the absolute and relative figures were drawn. (figs.8&9). In both Groups A and C the longest deviation from the 'pre-exposure' level was a difference of 0.2 mm. In both cases this difference represented an improvement in performance and was recorded for the second reading, i.e. the first 'exposure' reading. The group average curves show a relative consistency in tactile sensitivity performance level, which, in the case of Group A is maintained for 50 minutes, and in the case of Group C for 100 minutes.

The improvement per subject over the period of testing only average 0.07 mm., a non-significant change. There was, however, a very definite improvement in the initial reading of this new trial compared with the initial reading of the previous trial carried out some time before. This improvement averaged 0.23 mm. per subject, which was highly significant (about the 0.5% level).

Similar graphs were drawn for the third group of subjects (Group D) who had not previously been tested in the cold. The group average curves show a definite bend towards improved performance on the two-point discrimination test. (See figs. 10 and 11). The gradual decrease in divider gap size was not accompanied by any significant tendency to return to the initial, or so called 'pre-exposure' level, gap-size. The largest decrease in average gap size of 0.30 mm. was recorded at the end of 40 minutes 'exposure'. This represents a decrease from 2.37 mm. to 2.07 mm., a significant change at about the 3% level.

A degree of similarity was noticed between the first portions of Group D's average curve and those for Groups A and C. After the initial reading had been recorded for both groups, a relatively rapid rate of improvement in tactile sensitivity occurred within the first 10 minutes. This rapid decrement in gap-size was then followed by a further 10 minute period of very slight or no-improvement, and finally by a further 10 minute period of relatively rapid improvement again. (Table B).

Table B. Comparison of Average Tactile Sensitivity Levels for Groups A and C subject to cold exposure, and Group D at Room Temperature during the first 30 minutes of testing.

Group	Initial Reading	Level after 10 mins.	After 20 mins.	After 30 mins.	Initial Reading	Rate of Decrease 10 mins.	Rate of Decrease 20 mins.	Rate of Decrease 30 mins.
D Exp. II	2.37 mm	2.26 mm	2.27 mm	2.16 mm	0	0.11	0.01	0.11
C Exp. I	2.02 mm	1.91 mm	1.87 mm	1.73 mm	0	0.11	0.04	0.14
A Exp. I	2.22 mm	2.08 mm	2.04 mm	1.90 mm	0	0.14	0.04	0.14

The individual curves of Group D show a somewhat varied response to the second experiment (fig.12). 5 of the 12 subjects show a fairly marked improvement throughout the testing period, the decrement in gap-size at the end of the testing period differing from the initial level by as much as 0.6 to 1.35 mm. 2 of the subjects show an impaired level of performance which increases during the testing period, the final levels differing by 0.6 to 0.3 mm. from the initial levels, while the remaining 5 subjects maintain a fairly level performance, tending towards a small decrease in requisite gap-size.

3. Experiment 3 - Results, Tactile Sensitivity.

Although all 6 subjects in Group D had already been tested for a period of 60 minutes at room temperature on the Dividers Test, the group average curve (See figures 13 and 14) showed a further improvement in performance for the first 40-50 minutes of the third experiment. This improvement was a decrease in gap-size of 0.46 mm. (From 203 to 1.57 mm - a change significant at the 3% level). At the end of the exposure period of 50 minutes, the final average recording was 1.55 mm. which cannot be regarded as a significant change in performance level from that reached after 40-50 minutes testing at room temperature. There were fluctuations in performance during the cold exposure, but the longest of these fluctuations does not exceed a change in performance level of more than 0.08 mm.

It may be of interest to note that the group average curve in this experiment exhibits the same phenomenon as that to which attention was drawn in the data summarised in Table B.

Tables VII, VIII and IX set out the relevant statistical data for this section of the report. Analysis of variance carried out on data from Groups D and C which were combined in a balanced arrangement, showed that there were only two significant terms in this analysis - the 'between subjects within groups' term and the 'between learning and no learning' term. The significance of the 'learning factor' in this analysis makes it probable that similar improvement in the earlier experiments was also influenced by this factor.

Experiment 3. Results. Manual Dexterity

The curve plotted for Group D from the averages of individual performance on the Peg Test showed an improvement in performance throughout the first 50 minutes of the experiment. (See Figures 15 and 16). The average initial reading of 31.2 seconds, may be compared with the 50 minute reading of 28.1 seconds, an average improvement of 3.1 seconds. This is significant at the 2% level. During the second part of the experiment, when readings were taken at 10 minute intervals (cf, Experiment 1) a constant deterioration in performance was recorded. The largest average time taken to perform the test -

31.2 seconds - was recorded after 30 minutes exposure. This was a deterioration significant at about the 3% level.

VI. Conclusions

Three main conclusions, each of general and practical importance, are to be drawn from these experiments. They are:-

1. Exposure to temperatures of -10°C to -15°C, without air movement for periods of half an hour and upwards interferes with manual dexterity. Skill of this kind begins to take longer to carry out very soon (ten minutes or so) after initial exposure. The effects tend to increase fairly rapidly at first but after the first half-hour or so, more slowly. On return to normal room temperature recovery is rapid but not immediate. Although it is true that in general the lower the skin temperature the more manual dexterity performance is hindered (Miller 1944), the one cannot be used as a direct index of the other.

2. The performance of tasks involving tactile sensitivity (as measured by the two-point discrimination technique) unlike that of tasks involving manual dexterity, appears to be relatively unaffected by mild low temperatures (-10°C to -15°C), in the absence of wind. The improvement recorded after successive applications of the two-point discrimination test, did not appear to be retarded, or in any other way impaired by the cold exposure.

3. Rapid change to a lower temperature, within the limits indicated, especially when it is accompanied by air disturbance, are especially likely to produce deterioration, or further deterioration, both of manual dexterity and of tactile sensitivity.

VII. Discussion

1. While it is clearly demonstrated that exposure to cold at a level of -10°C to -15°C, in still air, and with only the working hand unprotected, hinders manual dexterity, the experiments by themselves do not indicate clearly what precise mechanisms are involved. They do suggest that it is unlikely that the fall-off is chiefly due to diminished tactile sensitivity, but even this is not quite clear. The most definite positive indication is that the principal loss is directly due to the relative functional inefficiency of the thumb under these conditions. However if the two-point discrimination test had been applied to the thumb instead of the index finger, the results might have been different. But at the same time the likelihood of a change of results occurring would not seem to be very great, for Franz and Kilduff showed that localised training in tactile discrimination gave rise to widespread improvement in other parts of the body which had not previously been trained, and this finding would seem to be partly borne out by the improved level of initial performance in tactile discrimination as comparing the initial reading of Groups A and C in Experiment 1 with those in Experiment 2.

Another possibility also requires further exploration. The disability might be due to some failure to use the information which normally tells an operator about the amount, speed and direction of his movements. There are forms of manual control, many of which occur in flying, which do not involve differential finger dexterity, but which do require accurate movement. If these turned out to be similarly affected under the same conditions the case for some breakdown of kinaesthetic 'feed back' would be greatly strengthened.

There is a third possibility and this seems the most likely one. It may well be that whenever accurate movements have to be made by two or more members of the body working together, if their normal relative functional efficiency is disturbed, the accuracy of movement suffers in a marked way. In this special case the thumb suffers, but the index finger remains perhaps little affected. It would not be difficult to devise other experiments setting up different types of change in the relative functional efficiency of simultaneously working parts of the body. Such experiments are very much needed both for theoretical and for practical reasons.

Meanwhile it is certainly a gain to have been able to demonstrate that manual dexterity suffers under even these, not very severe, low-temperature conditions, but that loss is not likely to be very great unless exposure is fairly long continued.

2. By far the most interesting of the results of the experiments, however, is that which shows that tactile sensitivity may improve, or continue to improve, within limits, in spite of the loss of dexterity. It is true that statistical analysis appears to show that the improvement cannot be directly attributed to the cold, but it cannot be contested that it takes place and therefore that there is nothing within the limits of the times and temperatures concerned in these experiments which stop it, although it has already been shown by Mackworth (1952) and others that longer exposures or more severe cold conditions certainly do stop it.

Once again, however, when we come to consider possible underlying mechanisms it becomes clear that these experiments have opened up problems that must be attacked by different methods.

One possibility is that local physiological conditions make tactile discrimination somewhat easier. For this there is not much evidence except the reports by the subjects that the point stimulations seemed to be more sharply defined in the cold. It is, however, possible that a temporary increase of the difference between skin temperature and the temperature of the Divider points might have this effect and this would be consistent with the relatively short duration of the improvement. This hypothesis could be tested, but would demand a special instrument after the style often used to explore temperature sensations. In any case it does seem important to settle this matter since it is possible that normal temperature effects could be checked, or reversed, by controlling the temperature of working tools.

A second possibility is that exposure to the cold produced an unwitting increase of effort and that the improvement was the direct result of this. Such an explanation would also be consistent with a rapid return to pre-exposure levels of performance on the termination of exposure in the cold chamber. The improvement, that is to say, could be specific to particular environmental conditions.

The principal difficulty in this hypothesis is that if the improvement was due to increased effort - "stronger motivation" - a similar improvement might well have been expected to take place for tasks requiring voluntary movement. It is true that in many instances, performance of the dexterity tasks was comparatively little affected by the cold exposure and it is possible that in these cases there was some influence of increased effort working against the normal deterioration effect. A further experiment involving accurate voluntary movement but without those forms of dexterity involving the thumb might be performed. If, then, a similar improvement occurred the case for unwitting increase of effort would be strengthened.

This second possibility leads to, and, in fact partially overlaps, a third - that, either stimulated by the cold (stress) conditions, or continuing a process started but not completed during the pre-exposure period, there was some genuine learning process as a result of which characteristics belonging to the two-point discrimination stimulation but not at first utilised by the subject, became effective. The tendency to return to pre-exposure levels of performance on leaving the cold chamber would not be an obstacle here since whatever has been gained by learning may be thrown out for a while by any marked change of environmental conditions. There is little doubt that a process of perceptual learning does in fact take place, and that it differs in some ways from the more commonly studied motor learning. But so far all attempts made in similar cases to identify, or even to demonstrate the occurrence of cues, which at first pass unnoticed, but later are used to increase efficiency (e.g. Mackworth 1952) have been unsuccessful. Yet the fact that considerable individual and group differences occurred in all the performances required by these experiments must be interpreted to mean that there were a number of different cues operating in the stimulation conditions and that these were being used differently, or different ones were being used, on different occasions. These are the general conditions under which both 'improvement' and 'learning' can take place. But there is at present no psychological understanding of how, or by what mechanisms, these conditions operate in the case of perception. By demonstrating that improvement does take place at threshold level in two-point tactile discrimination - whether or not as a result of exposure to stress conditions - these experiments raise in an acute form the whole problem of perceptual learning, with its vitally important theoretical and practical implications.

3. The deterioration which quickly followed change from a low to a perceptibly lower temperature, accompanied by air disturbance, requires some form of explanation. It is possible that the cutaneous receptors involved in the performance of two-point discrimination function normally up to a certain critical point, after which some of the relevant receptors cease to function, and this is accompanied by an immediate deterioration in

performance. The actual mechanism leading to failure of normal function on the part of the sense organs, might be due to a form of 'summation effect', the sudden change in environmental conditions acting as a stimulus for the production of an agent or agents which gradually increase in concentration until the local receptors are prevented from playing their normal role.

It should, however, be noted that the group average curves plotted from individual skin temperature readings in the first experiment did not show any significant change after the 30-40 minute cold exposure period, although some of the individual curves do show a further drop in skin temperature. It might have been supposed that any change in performance level on the tactile sensitivity test, if due to the sudden change in cold conditions, would have been reflected by the skin temperature readings, but the variation between subjects may account for a failure on the part of the group average curves to show this. The results here again emphasise the importance for human behaviour of sudden change in environmental conditions. It is in fact rapid change, rather than absolute level, of stress that is significant.

Modern flying produces a large number of situations in which rapid change in environmental conditions at high stress is a prominent character. Unfortunately behaviour adaptations which swiftly follow change of this kind are apt to remain unnoticed at the time, and to pass without comment later. It seems not too much to say that they never will be either properly appreciated or understood, unless they are made a subject of specific and planned experimental attack.

ACKNOWLEDGMENTS

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A.

Selection of the Tests

TABLE IA

Correlations between 4 Manual Dexterity tests completed by 20 subjects at Room Temperature. (Figures in brackets give level of significance of association.)

Test \ Test	Unscrewing Nuts	Peg	Screwdriver (Unscrewing)	Screwdriver (Screwing up)
Unscrewing Nuts	-	0.57 (0.002)	0.33 (0.1)	0.50 (0.01)
Peg	0.57 (0.002)	-	0.35 (0.08)	0.68 (0.001)
Screwdriver (unscrewing)	0.33 (0.1)	0.35 (0.08)	-	0.31 (not sig. at 0.1)
Screwdriver (Screwing up)	0.50 (0.01)	0.68 (0.001)	0.31 (not sig. at 0.1)	-

TABLE I(b)

Correlations between 3 Tactile Sensitivity tests completed by 20 subjects at Room Temperature. (Figures in brackets give level of significance of association.)

Test \ Test	V	Pointers	Hole
V	-	0.61 (0.001)	0.43 (0.05)
Pointers	0.61 (0.001)	-	0.55 (0.01)
Hole	0.43 (0.05)	0.55 (0.01)	-

Experiment 1. - Manual Dexterity

Derived figures from the actual results are presented in the following tables. Since the average times (in secs.) to perform the Unscrewing nuts, Peg, Screwdriver (unscrewing) and Screwdriver (screwing up) tests under room-temperature conditions were approximately inversely proportional to $5\frac{1}{2}$, 7, 2 and 1, these factors were used to multiply times of performance and so make the tests comparable with each other. This was necessary in order to apply the analysis of variance technique subsequently carried out.

Time (in secs.) for Group A to perform the Manual Dexterity tests at room temperature and after cold exposure (½ hour).

Test	Subject / Temp.	1	2	3	4	5	6	Total
Unscrewing Nuts	Room	187	231	193	264	187	264	1326
	Cold	231	291	275	214	330	308	1649
Peg	Room	196	224	287	238	189	217	1351
	Cold	210	210	231	224	210	203	1288
Screwdriver (unscrewing)	Room	152	240	202	230	182	280	1286
	Cold	180	280	192	146	220	314	1332
Screwdriver (screwing up)	Room	160	190	192	248	146	210	1146
	Cold	159	235	231	234	165	204	1228
Total	Room	695	885	874	980	704	971	5109
	Cold	780	1016	929	818	925	1029	5497

TABLE II(b)

Time (in secs.) for Group B to perform the Manual Dexterity tests at room temperature and after cold exposure (1 hour).

Test	Subject / Temp.	7	8	9	10	11	12	Total
Unscrewing Nuts	Room	182	275	160	253	192	242	1304
	Cold	182	319	583	605	236	357	2282
Peg	Room	217	224	210	231	210	210	1302
	Cold	196	231	350	287	231	231	1526
Screwdriver (unscrewing)	Room	306	234	184	214	214	230	1382
	Cold	240	370	472	522	320	278	2202
Screwdriver (screwing up)	Room	226	263	189	249	313	251	1491
	Cold	207	296	358	308	326	253	1748
Total	Room	931	996	743	947	929	933	5479
	Cold	825	1216	1763	1722	1113	1119	7758

Time (in secs.) for Group C to perform the Manual Dexterity tests at room temperature and after cold exposure ($1\frac{1}{2}$ hours).

Test	Subject / Temp.	13	14	15	16	17	18	Total
Unscrewing Nuts	Room	269	154	275	220	269	203	1390
	Cold	352	182	423	352	308	599	2216
Peg	Room	350	196	175	217	280	175	1393
	Cold	287	217	196	273	280	406	1659
Screwdriver (unscrewing)	Room	272	150	242	210	294	180	1348
	Cold	362	222	306	348	445	410	2094
Screwdriver (screwing up)	Room	233	157	231	221	321	185	1348
	Cold	513	175	256	293	304	570	2111
Total	Room	1124	657	923	868	1164	743	5479
	Cold	151..	796	1181	1266	1138	1985	8080

The variables which may effect the recorded times are:-

(1) The test performed
(2) The temperature
(3) The period for which the subject experienced the cold temperature
(4) The subject himself.

and these variables and associated interactions between them have been investigated by a conventional analysis of variance technique. From this analysis the following table was constructed.

TABLE III

Analysis of Variance of data on Manual Dexterity tests summarised in Tables II(a), (b) and (c).

Source of Variation	Sum of Squares	d.f.	Mean Square	F
Between Groups (G)	94406	2	47203	21.81^{xx}
Between Tests (K)	46366	3	15455	7.14^{x}
Between Temperatures (T)	207784	1	207784	96.02^{xxx}
Interaction (G x K)	17000	6	2833	1.31
Interaction (G x T)	48601	2	24300	11.23^{xx}
Interaction (K x T)	48125	3	16042	7.41^{x}
Residual Error (1)	12987	6	2164	
Between Subjects within Groups (S)	231032	15	15402	4.65^{xxx}
Interaction (K x S)	127711	45	2838	0.86
Interaction (T x S)	228241	15	15216	4.59^{xxx}
Residual Error (2)	99359	30	3312	
TOTAL	1161612	143		

x Significant at 5% level
xx Significant at 1% level
xxx Significant at 0.1% level

The analysis is slightly complicated by the fact that each subject performed the tests for only one of the three different exposure periods. Hence it is not possible to obtain an overall significance test between subjects but only on subjects within groups. This also affects the interactions which include subjects as a variable.

It may be seen that the following differences were significant:-

(1) Between Tests (K) (5% level)

(2) Between Temperatures (T) (0.1% level)

(3) Between Groups (G) (1% level)

(4) Between Subjects within Groups (S) (0.1% level)

Also the following interactions showed significant differences:-

(5) G x T (1%)

(6) K x T (5%)

(7) T x S (0.1%)

The first four sources of variation may be expressed as follows:

(i) Performances varied from test to test.

(ii) Performances were slower in the cold than at room temperature.

(iii) Performances of Groups A, B, and C differed significantly.

(iv) Performances of some subjects were faster than others within a group.

The interactions significant may be stated thus:

(v) Performances deteriorated as the exposure period increased.

(vi) Performances deteriorated more on some tests than on others in the cold.

(vii) Performances of some subjects within a group deteriorated more than those of other subjects.

By the method used to equate the times of tests at room temperature, the result (i) shows, in effect, that performances vary from test to test <u>in the cold</u>. This is emphasised by (vi).

Conclusion (ii) - that cold conditions have a deleterious effect on tests of manual dexterity is substantiated by (v) which shows that this effect increases as length of exposure increases.

Conclusions (iii) and (iv) show how differently these tests are performed when attempted by a number of subjects. The group results varied (due obviously in part to the effects of different periods of cold exposure) but in view of the differences between 'subjects within groups' (iv) one suspects an additional variation due to 'subjects between groups'. This subject variation is further shown in their different reactions to the cold conditions (vii).

TABLE IV

Discrimination gap size (in mms.) for Groups A, B and C recorded for the Tactile Sensitivity test at Room Temperature (prior to entering the cold chamber), at the end of period of exposure to cold and finally Room Temperature when the subjects had 'returned to normal' as indicated by skin temperature.

Group	Subject / Temp.	1	2	3	4	5	6	Total
A	Room 1	2.10	1.75	2.30	1.85	2.65	2.70	13.35
	Cold	2.25	1.70	2.00	1.45	1.60	2.20	11.20
	Room 2	2.55	1.90	2.35	1.60	1.40	2.30	12.10
	Subject / Temp.	7	8	9	10	11	12	Total
B	Room 1	1.90	2.15	1.55	2.05	1.70	2.40	11.75
	Cold	1.60	1.70	1.70	1.45	1.80	2.05	10.30
	Room 2	1.90	1.90	1.75	1.65	1.80	2.10	11.10
	Subject / Temp.	13	14	15	16	17	18	Total
C	Room 1	1.80	1.75	1.70	2.15	2.30	2.50	12.20
	Cold	1.35	1.15	1.50	2.40	2.20	2.55	11.15
	Room 2	1.60	1.60	1.55	2.15	2.00	2.25	11.15
Total	Room 1	5.80	5.65	5.55	6.05	6.65	7.60	37.30
	Cold	5.20	4.55	5.20	5.30	5.60	6.80	32.65
	Room 2	6.05	5.40	5.65	5.40	5.20	6.65	34.35

An analysis of variance technique was applied to this data. From this analysis Table V was formulated.

TABLE V

Analysis of Variance of data on Tactile Sensitivity tests on 18 subjects at Room Temperature and under Cold conditions shown in Table IV.

Source of Variation	Sum of Squares	d.f.	Mean Square	F
Between Groups (G)	0.3462	2	0.1731	9.62[x]
Between Temperatures (T)	0.6151	2	0.3075	17.08[x]
Residual Error (1)	0.0719	4	0.0180	
Between Subjects Within Groups (S)	4.4569	15	0.2971	16.51[xxx]
Residual Error (2)	1.5414	30	0.0514	
Total	7.0315	53		

x Significant at 5% level. xxx Significant at 0.1% level

This table shows significant differences

(1) Between Groups (G) (5% level)
(2) Between Temperatures (T) (5% level)
(3) Between Subjects within Groups (S) (0.1% level).

Here it should be noticed that (1) showed Group A to be less sensitive than Groups B or C. Group B was the most sensitive of the three groups. Also that the subjects required a smaller gap size for two point discrimination during the exposure to the colder temperature, than during either the pre- or post-exposure periods.

The subjects themselves varied very significantly within a group and this unfortunately would tend to invalidate any judgment on group effects due to length of exposure.

The improvement in the cold being the most interesting factor, the data was sub-analysed into two further sections considering

(a) only pre-exposure and terminal exposure readings, and

(b) only terminal post-exposure, and terminal exposure readings.

Here the results showed significant improvement (5% level) in (a), see Table VI(a), but a non-significant improvement in (b), see Table VI(b).

TABLE VI(a)

Analysis of Variance of part of the data shown in Table IV concerned with pre-exposure period and cold chamber results.

Source of Variation	Sum of Squares	d.f.	Mean Square	F
Between Groups (G)	0.2606	2	0.1303	5.04
Between Temperatures (T)	0.6006	1	0.6006	23.23 x
Residual Error (1)	0.0517	2	0.0258	
Between Subjects within Groups (S)	3.4440	15	0.2296	3.81 xx
Residual Error (2)	0.9039	15	0.0603	
Total	5.2608	35		

x Significant at 5% level
xx Significant at 1% level

TABLE VI(b)

Analysis of Variance of part of the data shown in Table IV concerned with post-exposure period and cold chamber results.

Source of Variation	Sum of Squares	d.f.	Mean Square	F
Between Groups (G)	0.1506	2	0.0753	3.73
Between Temperatures (T)	0.0803	1	0.0803	3.98
Residual Error (1)	0.0405	2	0.0202	
Between Subjects within Groups (S)	3.8201	15	0.2547	10.66 xxx
Residual Error (2)	0.3591	15	0.0239	
Total	4.4506	35		

xxx Significant at 0.1% level

D. Tactile Sensitivity and Skin Temperature

There were 112 sets of reading of tactile sensitivity and skin temperature from the records of the 18 subjects. The number of readings per subject varied from 4 on some subjects in Group A to 9 on others in Group C. A correlation between these two measured quantities resulted in a value of 0.21 for the correlation coefficient which was significant at the 5% level, showing that cold conditions tended to produce increased sensitivity.

An attempt to eliminate a certain amount of the heterogeneity of this data by reducing the number of readings per subject to 3, the initial test reading, the reading after 30 mins. exposure, and the final test reading after leaving the cold chamber, resulted in a coefficient of 0.29, again significant at the 5% level.

In an effort to avoid any possible 'learning' factor, the reading after 30 mins. exposure and the final test reading were used, giving a coefficient of 0.31, nearly significant at the 5% level.

E. Experiment 3. - Tactile Sensitivity.

For this analysis of the results of Group D were combined with corresponding values of Group C to form the balanced arrangement shown in Table VII. This gives the results for Group D using:

(a) The first five readings at room temperature, including a possible 'learning factor'.

(b) The final pre-exposure reading and the first four exposure readings, thus excluding any 'learning factor'.

Group C has the contrasting arrangement of:

(a) The pre-exposure reading and four subsequent exposure readings, including a possible 'learning factor'.

(b) The five consecutive room temperature readings following a 50 minute test period, thus excluding any 'learning factor'.

TABLE VII

Tactile Sensitivity (in mms.) of Groups C and D for two 40 minute periods under varying conditions.

Group	Subject	Cold (with learning)					Room Temperature (without learning)				
		Pre-exposure	10	20	30	40	0	10	20	30	40
	13	1.80	1.30	1.35	1.15	1.20	1.60	1.40	1.65	1.50	1.50
	14	1.75	1.55	1.50	1.35	1.35	1.55	1.45	1.55	1.55	1.40
	15	1.70	1.55	1.45	1.30	1.50	1.70	1.80	1.80	1.70	1.50
C	16	2.15	2.25	2.30	2.05	2.50	2.00	2.10	2.20	1.90	1.90
	17	2.30	2.30	2.25	1.80	2.15	2.30	2.40	2.40	2.75	2.60
	18	2.50	2.50	2.30	2.65	2.75	2.50	2.60	2.50	2.50	2.65
Group	**Subject**	**Room Temperature (with learning)**					**Cold (without learning)**				
		0	10	20	30	40	Pre-exposure	10	20	30	40
	19	2.80	2.00	2.35	2.10	2.00	1.05	1.30	1.30	1.15	1.45
	20	2.30	2.30	2.00	1.75	1.90	1.05	1.10	1.40	1.00	1.30
	21	1.90	2.05	2.20	2.15	2.05	1.75	1.40	1.70	1.65	1.45
D	22	2.60	2.45	2.20	1.95	2.05	2.10	1.70	2.20	1.95	1.65
	23	2.80	2.60	2.70	2.70	2.55	1.95	1.90	1.50	1.85	1.80
	24	2.50	2.70	2.70	2.65	2.45	1.55	1.65	1.40	1.50	1.70

A reduction of Table VII to relative values, the initial reading of each experience being made zero (0) as shown in Table VIII.

Reduction of Table VII to deviations (in mms.) from initial values in Cold or at Room Temperature whichever is appropriate. (Negative values indicate increased sensitivity.)

Group	Subject	Cold (with learning)					Room Temperature (without learning)				
		Pre-Exposure	10	20	30	40	0	10	20	30	40
C	13	0	-0.50	-0.45	-0.65	-0.60	0	-0.20	0.05	-0.10	-0.10
	14	0	-0.20	-0.25	-0.40	-0.40	0	-0.10	0.00	0.00	-0.15
	15	0	-0.15	-0.25	-0.40	-0.20	0	0.10	0.10	0.00	-0.20
	16	0	0.10	0.15	-0.10	0.35	0	0.10	0.20	-0.10	-0.10
	17	0	0.00	-0.05	-0.50	-0.15	0	0.10	0.10	0.45	0.30
	18	0	0.00	-0.20	0.15	0.25	0	0.10	0.00	0.00	0.15

Group	Subject	Room Temperature (with learning)						Cold (without learning)			
		0	10	20	30	40	Pre-Exposure	10	20	30	40
D	19	0	-0.80	-0.45	-0.70	-0.80	0	0.25	0.25	0.10	0.40
	20	0	0.00	-0.30	-0.55	-0.40	0	0.05	0.35	-0.05	0.25
	21	0	0.15	0.30	0.25	0.15	0	-0.35	-0.05	-0.10	-0.30
	22	0	-0.15	-0.40	-0.65	-0.55	0	-0.40	0.10	-0.15	-0.45
	23	0	-0.20	-0.10	-0.10	-0.25	0	-0.05	-0.45	-0.10	-0.15
	24	0	0.20	0.20	0.15	-0.05	0	0.10	-0.15	-0.05	0.15

An analysis of variance was carried out on this data. Complicated by the fact that the subjects were different in each group, and that was no clear dichotomy between room temperature and cold conditions, or between 'learning factor' and no 'learning factor' in either group, only a few of the many possible interactions could be computed. None of these proved to be significant at a high level of probability and were thus included in the 'residual error' terms.

Table IX shows the variation between the five main factors. It will be noticed that only two of them were at all significant, the 'between subjects within groups' term and the 'between learning and no learning' term. The subjects, as has been seen before, were very variable. The 'learning factor' also showing up significant at the 1% level indicated that the improvement found in Experiment 1 thought to be due to the cold conditions, was in fact influenced by the 'learning factor', a conclusion supported by the non significance of the 'between temperatures' term in this analysis. It should be remembered, however, that this work is concerned only with the first 40 minutes exposure at -10°C.

TABLE IX

Analysis of Variance carried out on the data in Table VIII (Non-significant interaction terms have been included in the Residual Error terms.)

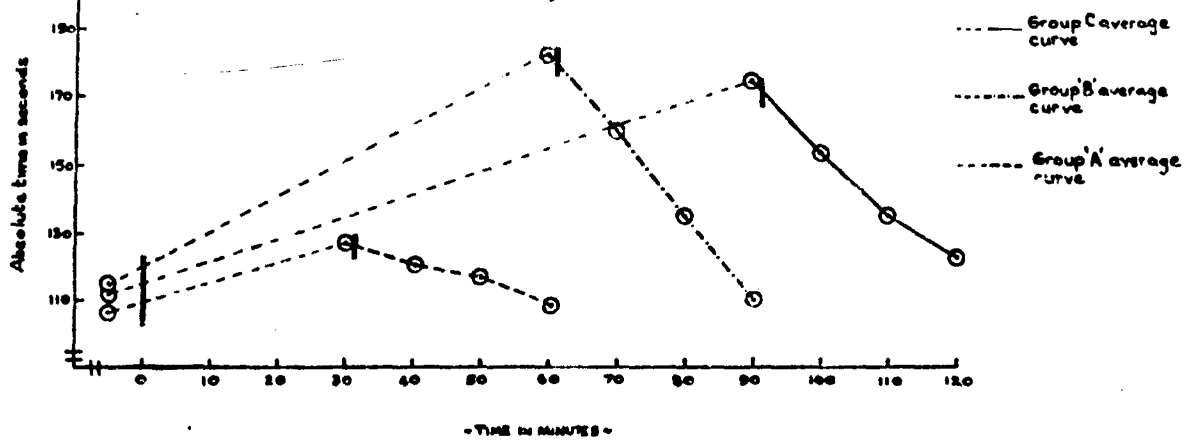
Source of Variation	Sum of Squares	d.f.	Mean Square	F
Between learning and no learning	0.9204	1	0.9204	11.31xx
Between Temperatures	0.0084	1	0.0084	0.10
Residual Error (1)	3.7447	46	0.0814	
Between Groups	0.0459	1	0.0459	2.42
Between Lengths of Exposure Period	0.1315	3	0.0438	2.31
Between Subjects within Groups	1.8878	10	0.1888	9.93xxx
Residual Error (2)	0.6273	33	0.0190	
Total	7.3660	95		

xx Significant at 1% level

xxx Significant at 0.1% level.

Screwdriver test unscrewing

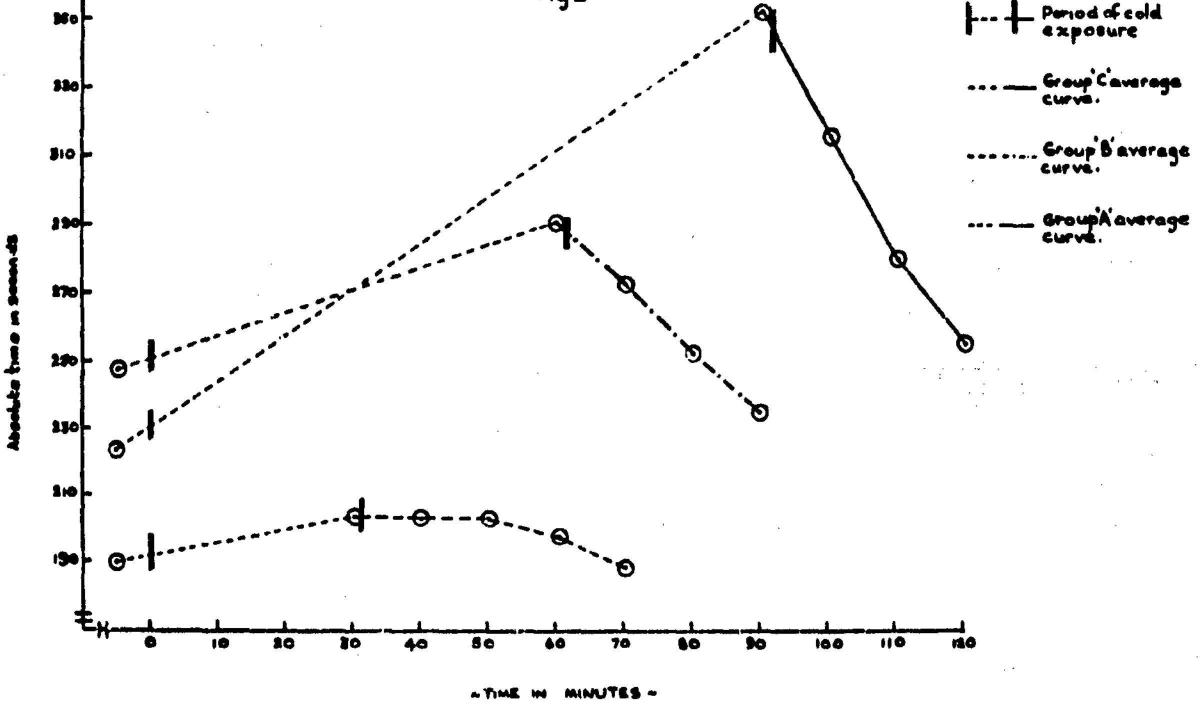
Fig 1



Manual dexterity Experiment 1

Screwdriver test - screwing in

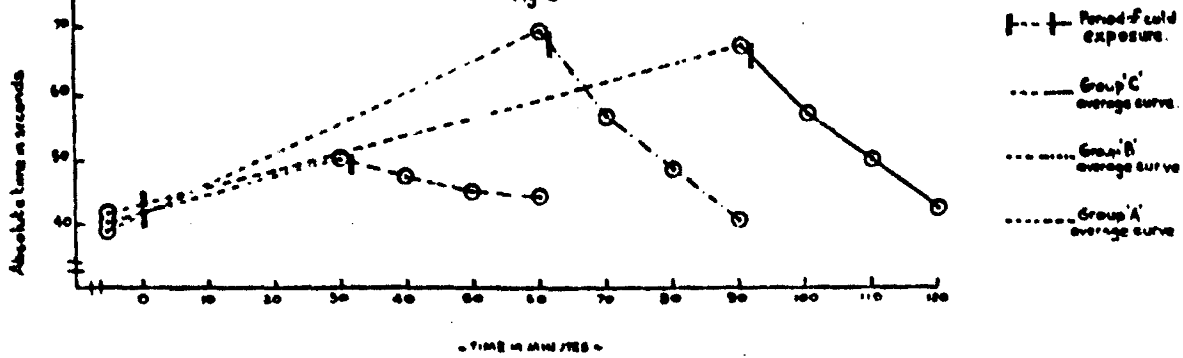
Fig 2

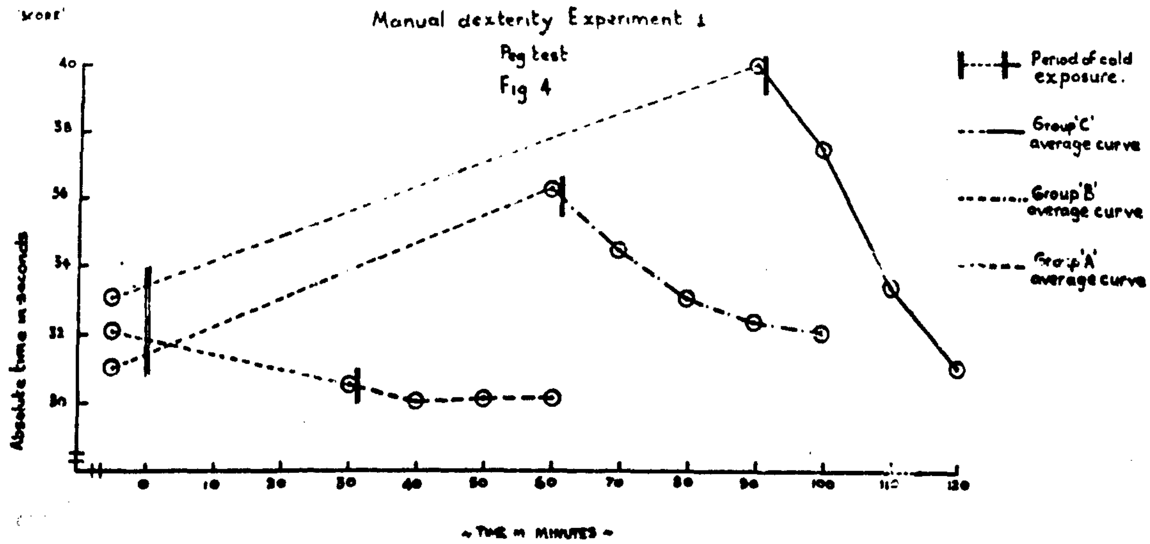


Manual dexterity Experiment 1

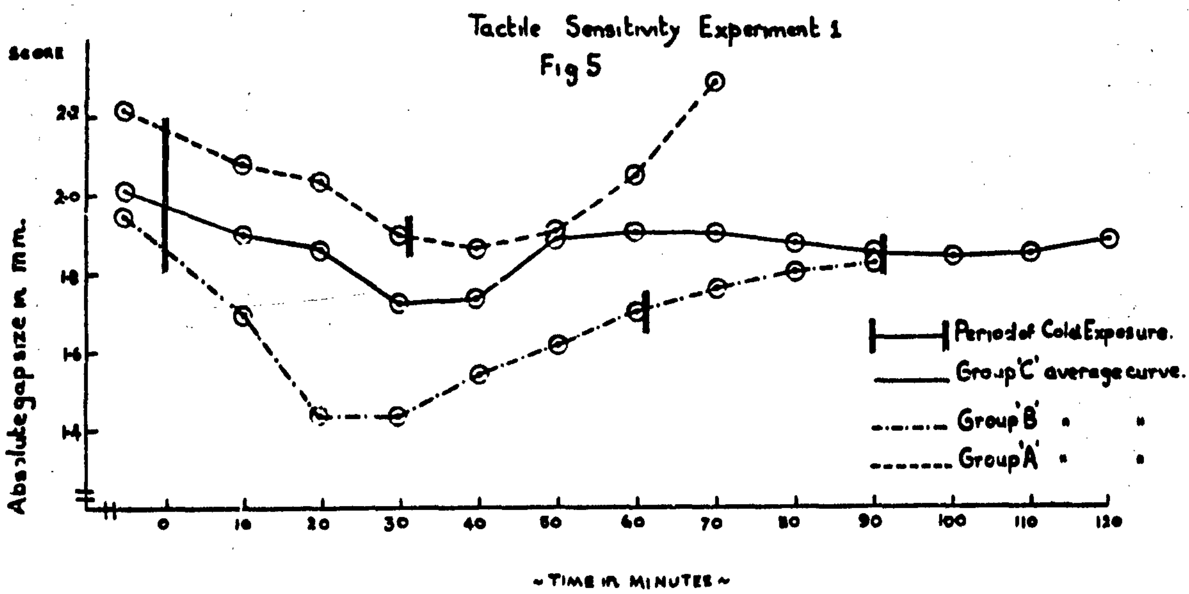
Nut and bolt test

Fig 3

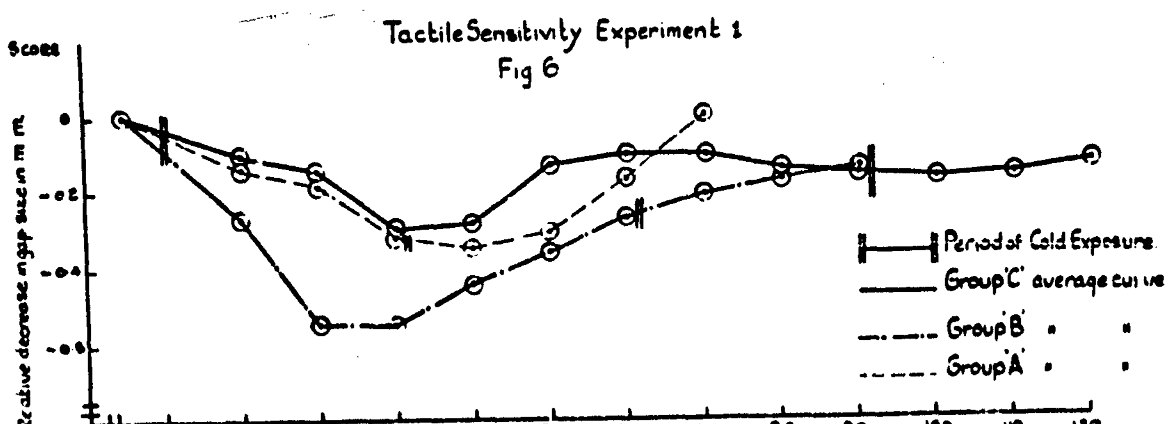




Score
Manual dexterity Experiment 1
Peg test
Fig 4
Period of cold exposure.
Group 'C' average curve
Group 'B' average curve
Group 'A' average curve
Absolute time in seconds
40
38
36
34
32
30
0
10
20
30
40
50
60
70
80
90
100
110
120
~ TIME IN MINUTES ~



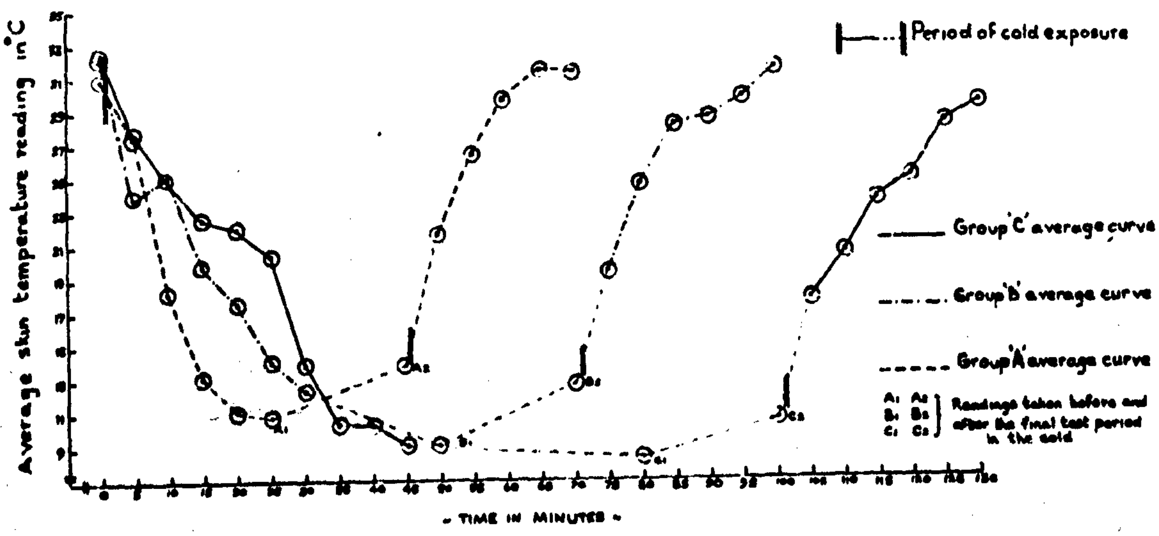
Tactile Sensitivity Experiment 1
Fig 5
SCORE
Absolute gap size in mm.
2·2
2·0
1·8
1·6
1·4
Period of Cold Exposure.
Group 'C' average curve.
Group 'B' " "
Group 'A' " "
0
10
20
30
40
50
60
70
80
90
100
110
120
~ TIME IN MINUTES ~



Tactile Sensitivity Experiment 1
Fig 6
Score
Relative decrease in gap size in m m.
0
-0·2
-0·4
-0·6
Period of Cold Exposure.
Group 'C' average curve
Group 'B' " "
Group 'A' " "
0
10
20
30
40
50
60
70
80
90
100
110
120.
~ TIME IN MINUTES ~

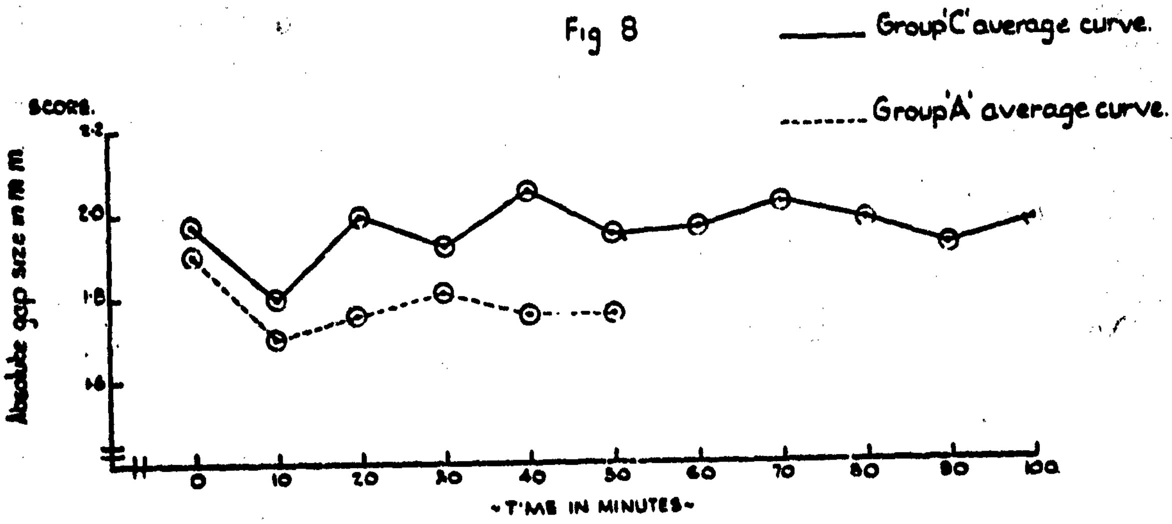
Skin temperature Experiment 1

Fig 7



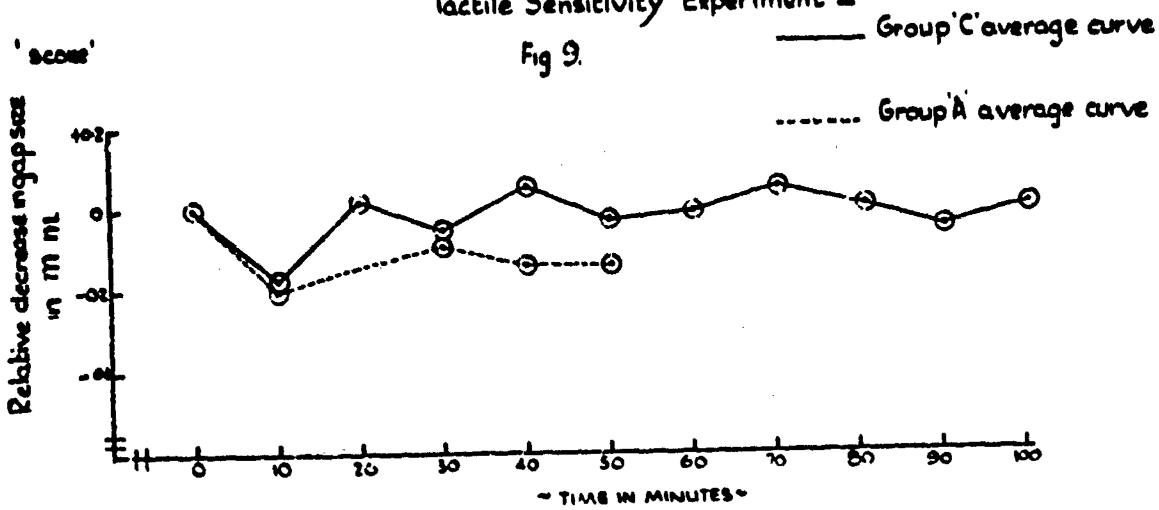
Tactile Sensitivity Experiment 2

Fig 8



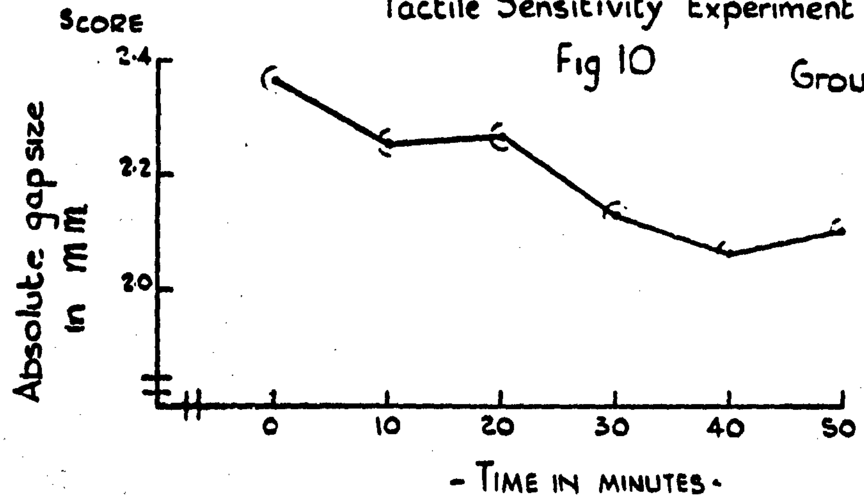
Tactile Sensitivity Experiment 2

Fig 9.



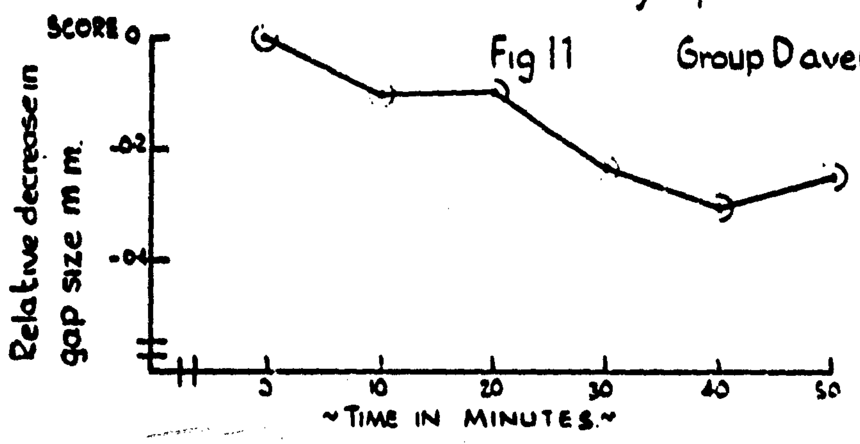
Tactile Sensitivity Experiment 2

Fig 10 Group D average curve.



Tactile Sensitivity Experiment 2

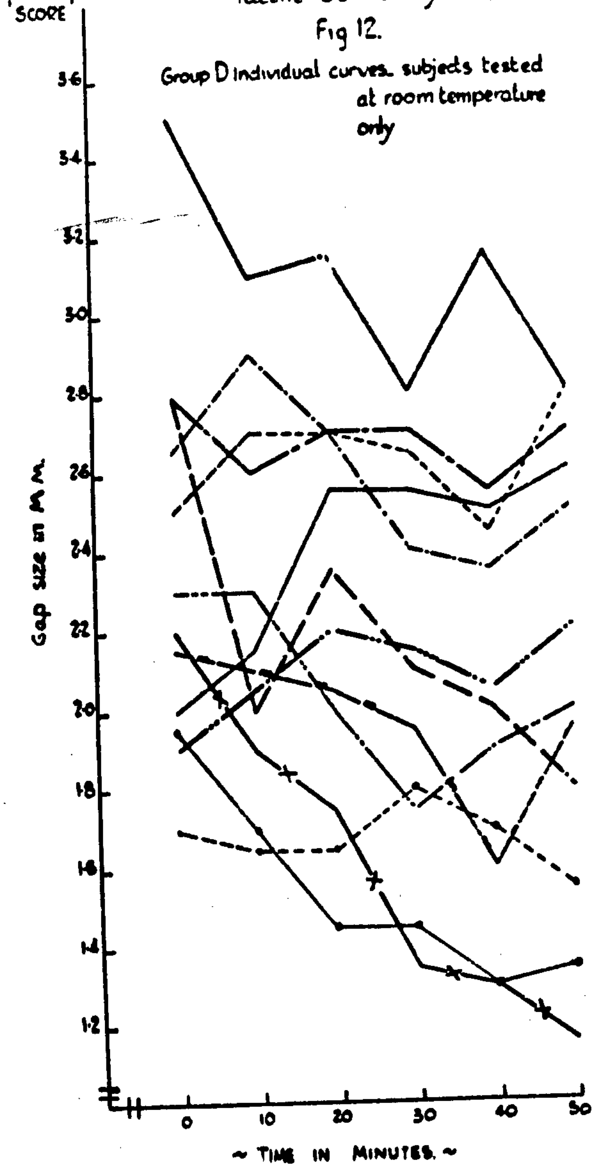
Fig 11 Group D average Curve.



Tactile Sensitivity Experiment 2

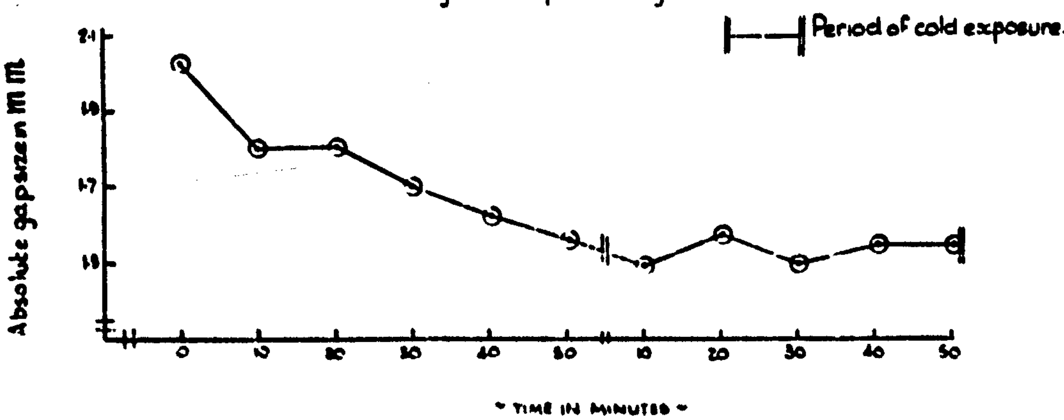
Fig 12.

Group D individual curves. subjects tested at room temperature only



Tactile Sensitivity Experiment 3

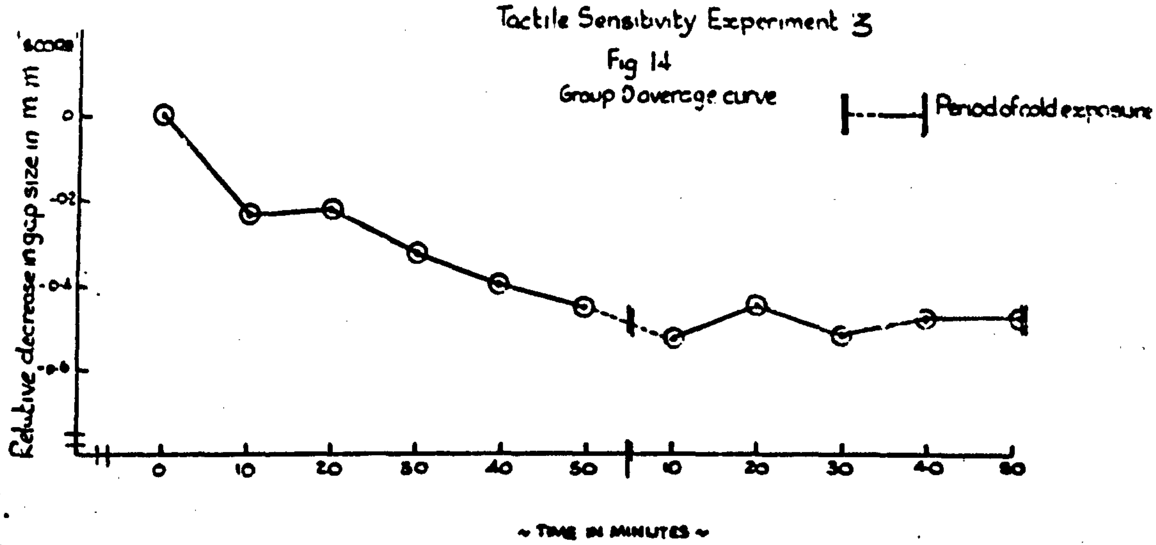
Fig 13 Group 'D' average curve.



Tactile Sensitivity Experiment 3

Fig 14

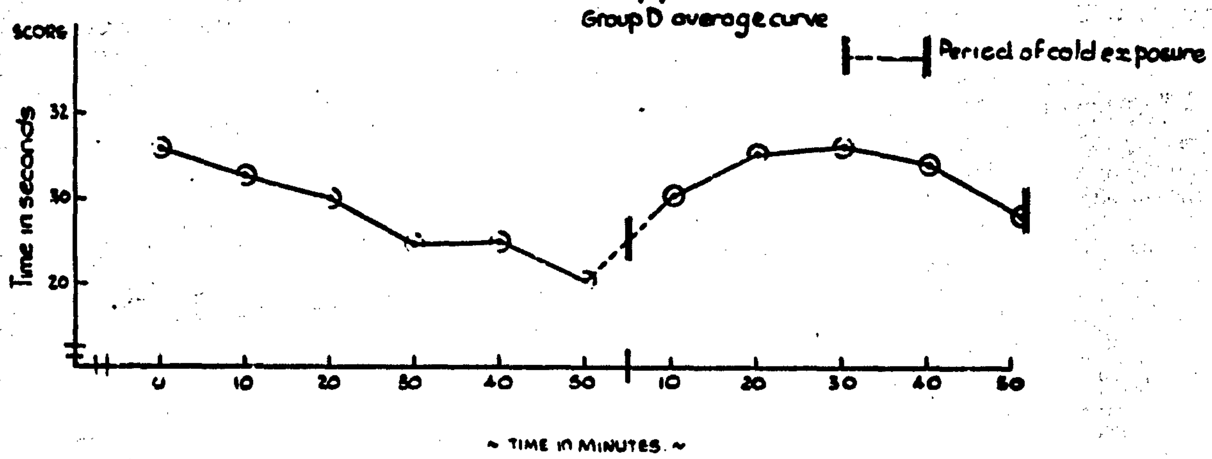
Group D average curve



Manual dexterity Experiment 3

Fig 15

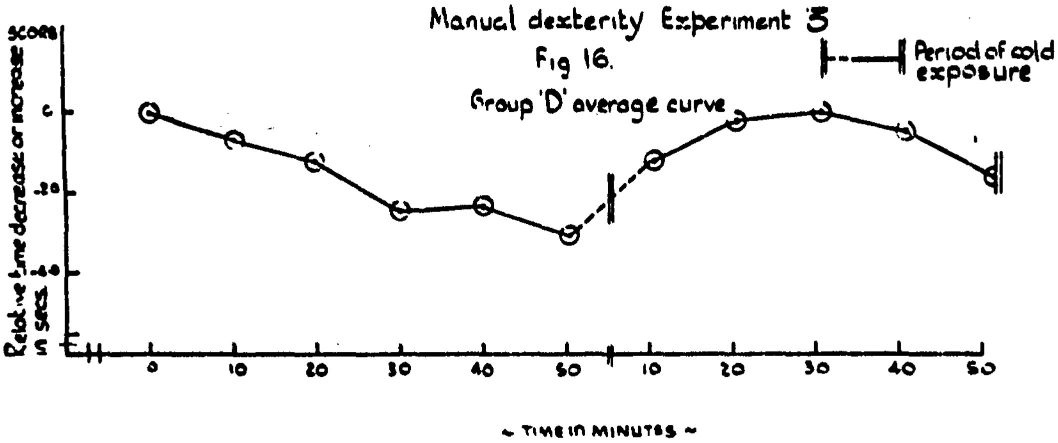
Group 'D' average curve



Manual dexterity Experiment 3

Fig 16.

Group 'D' average curve



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